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RESEARCH ARTICLE

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Effectiveness of inorganic and organic mulching for soil salinity and sodicity control in a grapevine orchard drip-irrigated with moderately saline waters

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Abstract

Soil mulching is a sensible strategy to reduce evaporation, accelerate crop development, reduce erosion and assist in weed control, but its efficiency for soil salinity control is not as well documented. The benefits of inorganic (plastic) and organic (grapevine pruning residues) mulching for soil salinity and sodicity control were quantified in a grapevine orchard (cultivars 'Autumn' Royal and 'Crimson') drip-irrigated with moderately saline waters. Soil samples were taken at the beginning and end of the 2008 and 2009 irrigation seasons in six vines of each cultivar and mulching treatment. Soil saturation extract electrical conductivity (EC_e), chloride (Cl_e) and sodium adsorption ratio (SAR_e) values increased in all treatments of both grapevines along the irrigation seasons, but the increases were much lower in the mulched than in the bare soils due to reduced evaporation losses and concomitant decreases in salt evapo-concentration. The absolute salinity and sodicity daily increases in 'Autumn' and 'Crimson' 2008 and in 'Crimson' 2009 were on the average 44% lower in the plastic and 76% lower in the organic mulched soils than in the bare soil. The greater efficiency of the organic than the plastic mulch in 'Crimson' 2009 was attributed to the leaching of salts by a precipitation of 104 mm that infiltrated the organic mulch but was intercepted by the plastic mulch. Although further work is needed to substantiate these results, the conclusion is that the plastic mulch and, particularly, the organic mulch were more efficient than the bare soil for soil salinity and sodicity control.

Additional key words: plastic mulching; plant-residues mulching; soil chloride; drip irrigation; water quality; *Vitis vinifera*.

Introduction

Mulches are frequently used in vegetable production to reduce evaporation losses from the soil surface, accelerate crop development in cool climates by increasing soil temperature, reduce erosion and assist in weed control. Mulches may be inorganic (generally thin sheets of polyethylene) or organic (generally plant residues such as straw). Plastic mulches reduce the evaporation of water from the soil surface by 50-80% (Allen *et al*., 1998). To a lesser extent, organic mulches also reduce the evaporation of water depending on its characteristics (particularly fragment size and thickness) (Diaz *et al*., 2005). Inorganic mulches are durable, but deteriorate with time and may generate disposal problems, whereas organic mulches are biodegradable, decompose more quickly and must be replaced more frequently than inorganic mulches.

As a consequence of reduced evaporation, soil mulching benefits the conservation of water, particularly in the topsoil, decreases the evapo-concentration of the salts present in the irrigation water and the soil solution (Zhang *et al*., 2008), and minimizes soil salinization and sodication (Chaudhry *et al*., 2004; Rahman *et al*., 2006).

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Abbreviations used: Cl_e (chloride concentration in the soil saturation extract); EC (electrical conductivity); EC_e (electrical conductivity in the soil saturation extract); ETc (crop evapotranspiration); ET_o (reference evapotranspiration); GWC (gravimetric soil water content); I (irrigation); LF (leaching fraction); P (precipitation); SAR_e (sodium adsorption ratio in the soil saturation extract).

These benefits would be particularly relevant in (i) arid or semiarid areas with high evaporative demand, (ii) soils or waters high in salts, and (iii) high-frequency, drip irrigation systems where the soil surface remains wetted for longer periods of time and therefore soil evaporation and salt evapo-concentration is exacerbated.

The effectiveness of soil mulching for soil salinity control has been documented in several annual crops, particularly in the last decade in China [Yang *et al*. (2006) in wheat; Zhang *et al*. (2008) in Swiss chard; Dong *et al*. (2009), Bezborodov *et al*. (2010) and Wang *et al*. (2011) in cotton; Pang *et al*. (2010) in a winter wheat-summer maize double cropping system; Wan *et al*. (2010) in cucumber; Morales-García *et al*. (2011) in bell pepper]. Chaudhry *et al*. (2004) evaluated in a saline and very high sodic soil planted with eucalyptus trees and irrigated with a sodic and moderately saline water, the effects of several mulches (bare and tilled soils, rice straw and plastic) on soil water content, salinity and sodicity. Soil salinity (EC_e, 0-15 cm soil depth) at the end of the trial decreased, relative to the initial EC_e, by 53% in the straw soil and 34% in the tilled soil, and increased by 5% in the plastic soil and 8% in the bare soil. Soil sodicity (SAR_e, 0-15 cm soil depth) decreased, relative to the initial SAR_e, by 45% in the straw soil, 30% in the tilled soil, 7% in the bare soil and 0.4% in the plastic soil. Although the reasons for these changes were not given, it could be speculated that the greater salinity reductions in the straw and tilled soils than in the plastic were due to the partial leaching of salts by rainfall that did not infiltrate the plastic-mulched soil. Soil sodicity decreased in all treatments and the greatest reduction in the straw-mulched soil was attributed to the presence of organic matter in this mulching material.

Although these studies have contributed to the assessment of soil mulching as a beneficial management strategy for soil salinity control, they were generally focused on the response of crops rather than on the rates of soil salinization along the irrigation season. Further, appraisal of the soil mulching-soil salinity relationships in drip-irrigated grapevines is not documented in the literature.

The objective of this work was to analyze the potential benefits of three mulching treatments (bare soil or control, inorganic and organic mulches) in alleviating soil salinization (total salts and chloride concentrations) and sodication (sodium adsorption ratio) in a grapevine orchard drip-irrigated with moderately saline waters.

Material and methods

The field trial was carried out in 2008 and 2009 in a four year-old table grape vineyard located in the Santa Barbara commercial orchard of the ALM Group, in the semi-arid county of Caspe (Zaragoza, Spain) (41.16°N, 0.01°W). Two seedless table-grape cultivars (*Vitis vinifera* cvs. 'Autumn Royal' and 'Crimson') were planted at a distance of 2.5 m between vines and 3.5 m between rows in two 0.5 ha adjacent sectors of the vineyard.

The vines were irrigated following the farmer's practices consisting in daily water applications at 100% of their net irrigation requirements by a single trickle line close to the vines with 2.2 L h^{-1} self-compensating emitters spaced 0.5 m. Volumetric water meters were installed to record the amount of irrigation water (I) applied. Similar irrigation depths were given to all mulching treatments, but the measured I values were somewhat lower in 'Crimson' than in 'Autumn' (data not given). The mean EC of the irrigation water was 1.46 dS m^{-1} in 2008 and 1.80 dS m^{-1} in 2009, and the main ions were Na^+, Ca^{2+}, Cl^- and SO_4^{2-}. The soils in the two sectors have similar characteristics and were classified as Xeric calcigypsid, coarse loamy, mixed (gypsic), thermic (Soil Survey Staff, 1999).

The climate was characterized using the daily data gathered in an automated agrometeorological station ("El Suelto-Plano Espés", 41.19° N, 0.05° W) of the Spanish National Network of Agrometeorological Stations for Irrigation (SIAR network). Fig. 1 shows the monthly and annual precipitations (P) recorded in the two study years. Crop evapotranspiration (ET_c) was determined for the bare soil using the reference evapotranspiration (ET_0) calculated with the Penman Monteith equation and the K_c values obtained from FAO's methodology (Allen *et al*., 1998).

The mulching treatments in 2008 and 2009 were bare soil (control) and soil under black polyethylene plastic. An organic mulch about 5 cm thick composed of grapevine pruning residues was also tested in 2009. The mulching materials were laid in the vine rows immediately after the initial 2008 and 2009 soil samplings to cover a width of about 0.6 m at both sides of the vines, and removed immediately before the final 2008 and 2009 soil samplings.

The variations in soil salinity along the 2008 and 2009 irrigation seasons were determined in the three mulching treatments of the 'Autumn' and 'Crimson' grapevines by sampling the soil at the beginning (26 March, except 'Crimson' 2009 that was sampled in

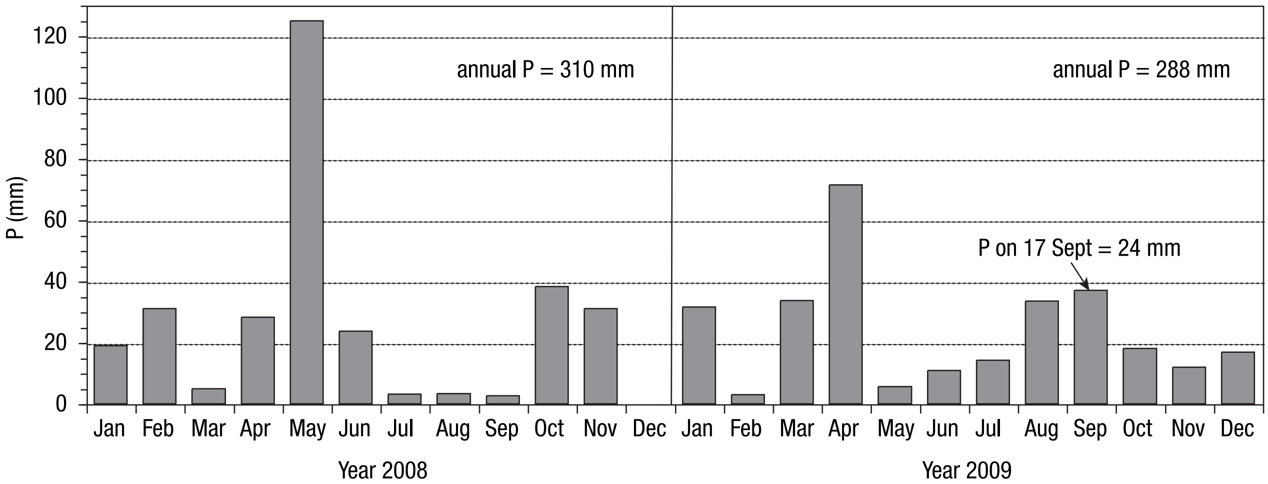

Figure 1. Monthly and annual values of precipitation (P) recorded in the experimental vineyard during the two study years. The P recorded on 17 September 2009 (the day before the final soil sampling in the 'Autumn' bare soil) is also given.

14 May due to logistic problems) and end (24 and 18 September in 'Autumn' 2008 and 2009, respectively, and 15 October in 'Crimson' 2008 and 2009) of each irrigation season. The 0-60 cm depth soil samples were taken with a 4 cm diameter Edelman auger in six vines (*i.e.*, replications) of each cultivar at 10 and 30 cm from a given emitter close to the vines. For simplicity and representativeness of root zone salinity, the results presented are the means of the values obtained at 10 and 30 cm from the emitter.

The collected soil samples were brought to the laboratory and analyzed for gravimetric soil water content (GWC) and soil saturation extract electrical conductivity (EC_e) in 2008 and 2009. Soil saturation extract chloride concentration (Cl_e) and soil saturation extract sodium adsorption ratio (SAR_e) were also determined in 2009. All the analyses were performed according to standard methods (Klute, 1986).

The statistical analyses were performed using Analysis of Variance (ANOVA) and General Linear Model (GLM) procedure of the SAS 9.1 software (SAS Institute, 2004). The means were separated using the Tukey's multiple comparison test at $p = 0.05$.

Results

Gravimetric soil water content (GWC)

Fig. 2a, 2b present the 2008 and 2009 initial and final irrigation season mean GWC measured in the bare, plastic and organic mulching treatments in 'Autumn' and 'Crimson' grapevines. Except for the bare soil, the differences between grapevines and mulching treatments were not different ($p>0.05$) due to the relatively high standard errors derived from the high spatial variability of soil water content typical in drip irrigation systems (Hanson, 2012).

The mean 2008 GWC was 18% higher in the plastic (GWC = 20.0%) than in the bare (GWC = 17.0%) treatment (Fig. 2a). The mean 2009 GWC values were 16% higher in the plastic (GWC = 19.1%) and 21% higher in the organic (GWC = 19.9%) treatments than in the bare (GWC = 16.4%) treatment (Fig. 2b). Thus, the two mulching materials reduced water evaporation from the soil and increased soil water content from values of about 17% in the bare soils to values of about 20% in the mulched soils, a value slightly lower than the measured field capacity (21%).

Soil salinity (EC_e)

Soil salinity increased along the 2008 irrigation season in the two mulching treatments and grapevine varieties (Fig. 2c). 'Crimson' soil salinity (mean EC_e = 5.0 dS m^{-1}) was twice that of 'Autumn' (mean EC_e = 2.6 dS m^{-1}), in agreement with the calculated field-wide leaching fractions [LF = $(I + P - ET_c) / (I + P)$] for the bare soil that were 12% in 'Crimson' and 19% in 'Autumn' (values for the periods in between initial and final soil samplings). These LF differences were due to the 6% lower I and 6% higher ET_c in 'Crimson' than in

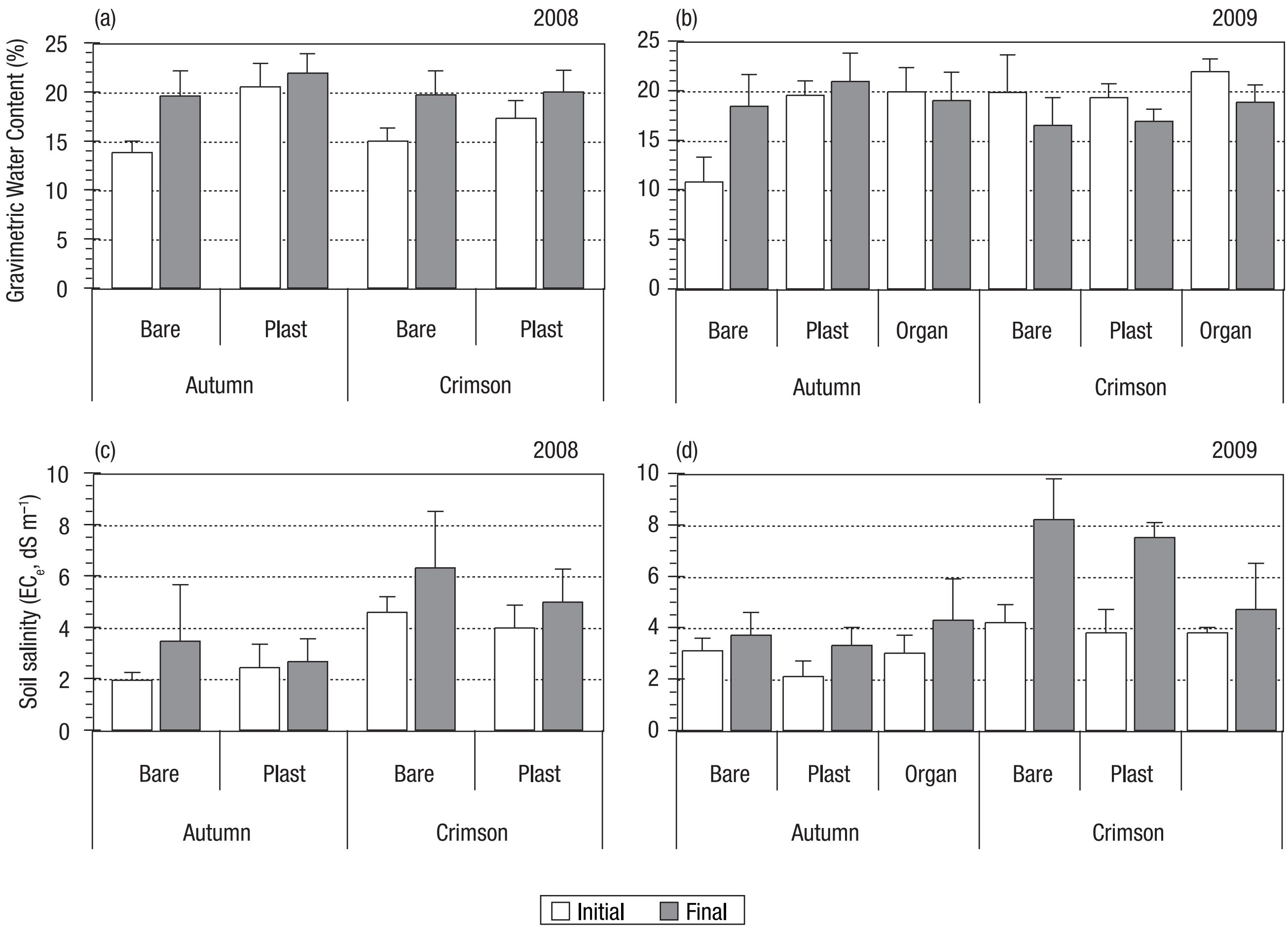

Figure 2. 2008 and 2009 initial and final irrigation season gravimetric soil water content (a and b) and soil salinity (EC_e) (c and d) measured in the bare (Bare), plastic (Plast) and organic (Organ, only for EC_e) soil mulching treatments in 'Autumn' and 'Crimson' grapevines. Vertical bars represent one standard error of the mean.

'Autumn' (data not given). Salinity increases were lower in the soil under plastic (initial and final EC_e values not different at $p > 0.05$) than in the bare soil (initial and final EC_e values different at $p < 0.05$). Thus, the relative EC_e increases along the 2008 irrigation season in the bare soil were 77% ('Autumn') and 38% ('Crimson'), as compared to 9% ('Autumn') and 25% ('Crimson') in the plastic mulched soil (Table 1).

The absolute daily EC_e increases, that take into account differences in sampling dates between cultivars and/or mulching treatments, were high and similar in the bare soil of both grapevines (0.008 dS m^{-1} day^{-1}) (Table 1). In contrast, the absolute daily EC_e increases in the plastic mulched soil were lower than in the bare soil and different in both grapevines (0.001 and 0.005 dS m^{-1} day^{-1} in 'Autumn' and 'Crimson', respectively. Based on the absolute increases obtained in the bare soil, the salinity increases in the plastic mulch were 85% and 43% lower in 'Autumn' and 'Crimson', respectively (Table 1).

Soil salinity also increased along the 2009 irrigation season in the three mulching treatments and grapevine varieties (Fig. 2d). 'Crimson' soil salinity (mean EC_e = 5.5 dS m^{-1}) was higher ($p < 0.05$) than 'Autumn' soil salinity (mean EC_e = 3.2 dS m^{-1}), in agreement with the calculated field-wide leaching fractions (21% in 'Crimson' and 30% in 'Autumn'; values for the periods in between initial and final soil samplings). These differences were due to the 10% lower I and 5% higher ET_c in 'Crimson' than in 'Autumn' (data not given). The absolute EC_e increases in 'Crimson' 2009 were highest in the bare soil (0.026 dS m^{-1} day^{-1}), intermediate in the plastic mulch (0.018 dS m^{-1} day^{-1}) and lowest in the organic mulch (0.005 dS m^{-1} day^{-1}) (Table 1). Based on the absolute increases obtained in

Table 1. Relative (Δrel) and absolute (Δabs) variations of soil saturation extract electrical conductivity (EC_e), chloride concentration (Cl_e) and sodium adsorption ratio (SAR_e) in the different mulching treatments (bare soil and soil under plastic and organic residues) along the 2008 and 2009 'Autumn' and 'Crimson' irrigation seasons. For Δabs, the percent changes in the plastic and organic mulches relative to the bare soil are also shown in parenthesis

			'Autumn'			'Crimson'		
			Bare	**Plastic**	**Organic**	**Bare**	**Plastic**	**Organic**
EC_e (dS m^{-1})	2008	[a]Δrel (%)	77	9	—	38	25	—
		[b]Δabs (dS m^{-1} day^{-1}	0.008	0.001	—	0.008	0.005	—
		(% change rel. to bare)		(–85%)			(–43%)	
	2009	[a]Δrel (%)	21	57	43	95	97	24
		[b]Δabs (dS m^{-1} day^{-1})	0.004	0.006	0.008	0.026	0.018	0.005
		(% change rel. to bare)		(50%)	(100%)		(–31)	(–81%)
Cl_e (mmol L^{-1})	2009	[a]Δrel (%)	78	109	85	307	343	118
		[b]Δabs (mmol L^{-1} day^{-1})	0.042	0.036	0.053	0.203	0.143	0.043
		(% change rel. to bare)		(–14%)	(26%)		(–30%)	(–79%)
SAR_e (mmol $L^{-1})^{0.5}$	2009	[a]Δrel (%)	48	63	44	183	198	146
		[b]Δabs [(mmol $L^{-1})^{0.5}$ day^{-1}]	0.008	0.012	0.012	0.047	0.033	0.015
		(% change rel. to bare)		(50%)	(50%)		(–30%)	(–68%)

[a] Δrel = 100 (EC_e, Cl_e, SAR_e final – EC_e, Cl_e, SAR_e initial) / EC_e, Cl_e, SAR_e initial. [b] Δabs = (EC_e, Cl_e, SAR_e final – EC_e, Cl_e, SAR_e initial) / numbers of days between sampling dates.

the 'Crimson' bare soil, the salinity increases were 31% and 81% lower in the plastic and organic mulches, respectively. In contrast, the absolute EC_e increases in 'Autumn' 2009 were lowest in the bare soil (0.004 dS m^{-1} day^{-1}) and increased by 50% and 100% in the soils with plastic and organic mulches, respectively (Table 1).

Soil chloride concentration (Cl_e)

The EC_e values given in the previous section could be affected by the precipitation of calcite and gypsum as the soil water evapo-concentrates. Thus, the Watsuit program (Wu *et al.,* 2012) showed that both minerals would precipitate in the soil at leaching fractions below 0.20 (data not given). In contrast, the chloride ion is not affected by mineral precipitation and, therefore, it may be considered a better tracer of soil water evapo-concentration.

Cl_e systematically increased ($p < 0.05$) along the 2009 irrigation season in both grapevines and, with the exception of the organic mulch, the final Cl_e concentrations were much higher in 'Crimson' than in 'Autumn' (Fig. 3a). The absolute daily Cl_e increases along the 2009 irrigation season were one order of magnitude higher than the corresponding daily EC_e increases (Table 1). The Δabs results obtained in 'Crimson' show, as for EC_e, that the efficiency for salinity control followed the order: organic > plastic > bare. However, the Δabs results obtained with Cl_e in 'Autumn' differed to those with EC_e, and the plastic mulch was more efficient for soil salinity control than the bare soil and the organic mulch (Table 1). Nevertheless, these results are not conclusive because, due to the high standard errors (Fig. 3a) typical in drip-irrigation systems (Hanson, 2012), the final and initial Cl_e in the 'Autumn' organic mulch were not different ($p > 005$).

Soil sodicity (SAR_e)

The initial SAR_e values were relatively low in all mulching treatments of both grapevines [all values below 5 (mmol $L^{-1})^{0.5}$] and increased consistently along the 2009 irrigation season, particularly in 'Crimson' (Fig. 3b). The Δabs daily SAR_e increases in 'Crimson' followed the same order than with EC_e and Cl_e: highest in the bare soil (0.047), intermediate in the plastic mulch (0.033) and lowest in the organic mulch (0.015). The relative SAR_e increases were also lower in the organic than in the other two treatments (Table 1).

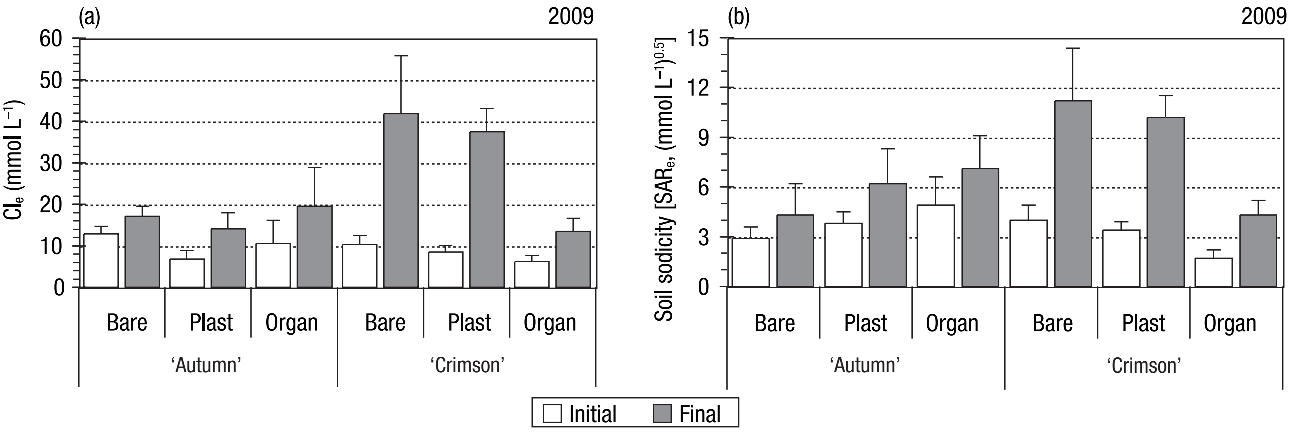

Figure 3. 2009 initial and final irrigation season soil chloride concentration (Cl_e) (a) and soil sodicity (SAR_e) (b) measured in the bare (Bare), plastic (Plast) and organic (Organ) soil mulching treatments in 'Autumn' and 'Crimson' grapevines. Vertical bars represent one standard error of the mean.

The results obtained in 'Autumn' show that soil sodication was much lower than in 'Crimson' with the exception of the organic mulch (Fig. 3b). The efficiency in controlling soil sodication was similar (in terms of absolute values) or lower (in terms of relative values) in the organic than in the plastic mulch, whereas as for EC_e soil sodication (Δabs) in 'Autumn' was lower in the bare soil than in the two mulching treatments (Table 1).

Discussion

The lower soil salinization (Δabs) in the plastic than in the bare soil in both years and grapevines (except in 'Autumn' 2009) (Table 1) was attributed to its lower evaporation and lower concentration of the salts applied with the irrigation water. The higher GWC in the plastic than in the bare soil (Figs. 2a,b) is in agreement with this statement. Tiware *et al.* (1998) indicated that the benefits of reduced soil evaporation were particularly significant in high-frequency drip irrigation systems where the soil surface remains wet most of the time.

The lower soil salinization in the organic than in the plastic mulch in 'Crimson' 2009 could be attributed to the partial leaching of salts by a recorded precipitation of 104 mm in between soil sampling dates that infiltrated the organic mulch but was intercepted by the plastic mulch. Thus, Fig. 2b shows that the final GWC in 'Crimson' 2009 was higher ($p < 0.05$) in the organic than in the plastic mulch as a consequence of precipitation. Chaudhry *et al.* (2004) also found that the straw mulch was more efficient than the plastic mulch for soil salinity control, and Yang *et al.* (2006) reported a higher soil water content using corn straw than plastic because of the 237 mm of precipitation recorded during the winter wheat growing period that was able to infiltrate the straw but not the plastic. Even though GWC were higher in the mulched than in the bare soil, vine yields were similar (data not given) because the irrigation depths were given in terms of the net irrigation requirements calculated for bare soils and without considering the lower soil evaporation in mulched soils.

As previously indicated, the results obtained in 'Autumn' 2009 were opposite to those obtained in 'Autumn' and 'Crimson' 2008 and in 'Crimson' 2009, since the bare soil was the most efficient treatment for soil salinity control (Table 1). In terms of the absolute daily EC_e values, the bare soil increased by 0.004 dS m^{-1} day^{-1}, as compared to increases of 0.006 and 0.008 dS m^{-1} day^{-1} for the plastic and organic mulches, respectively. An explanation for this apparent contradictory result is that a punctual precipitation of 24 mm was recorded the day before the final soil sampling (17 September; Fig. 1) in the bare soil of 'Autumn' 2009 that partially leached the accumulated salts in this treatment. This precipitation event was not relevant in the 'Crimson' bare soil because the final soil sampling was performed later (15 October). The lower soil salinity increase in the bare soil than in the plastic and organic mulched soils in 'Autumn' 2009 should therefore be taken with caution because it was an artifact derived from this punctual precipitation falling just before the final soil sampling.

The behavior of Cl_e was in general similar to that of EC_e, but the absolute daily Cl_e increases along the 2009 irrigation season were one order of magnitude higher than the corresponding daily EC_e increases (Table 1) due to the selective precipitation of calcium minerals and the concomitant decreases in EC_e (as shown by Watsuit, data not given). The final Cl_e concentration of about 40 mmol L^{-1} measured in the bare and plastic treatments of the 'Crimson' grapevine (Fig. 3a) were close or above the maximum permissible Cl_e concentrations of 40-30 mmol L^{-1} without grapevine leaf injury reported by Ayers & Westcot (1985). However, these Cl_e concentrations were averages of the 0-60 cm soil depth measured at 10 and 30 cm from emitters, whereas crops in drip-irrigation systems tend to extract the soil water closest to the emitters, where salt concentrations are lower and more similar to those of the irrigation water (Hanson, 2012). This behavior will explain that grapevine yields (data not given) were independent of mulching treatments.

Soil sodication (SAR_e) took place along the 2009 irrigation season, irrespective of the grapevine and mulching treatment (Fig. 3b). The absolute and relative SAR_e increases in 'Crimson' were lower in the organic than in the other two treatments (Table 1). Chaudhry *et al*. (2004) also demonstrated the benefits of organic mulching for soil sodicity control. In contrast, the bare soil in 'Autumn' was most efficient for soil sodicity control due to the already reported precipitation recorded the day before its final soil sampling.

Similar results were obtained in terms of soil salinization and soil sodication because they were correlated ($SAR_e = 1.31 \cdot EC_e - 0.2$; $R^2 = 0.667$, significant at $p < 0.001$) due to the selective precipitation of calcium minerals (particularly calcite and gypsum) with increases in soil salinity. Although not discussed in this work, it should be noticed that the final SAR_e values of about 10 (mmol $L^{-1})^{0.5}$ measured in the bare and plastic treatments of 'Crimson' grapevine (Fig. 3b) could be deleterious for soil structural stability when subject to low-salinity precipitation waters (Ayers & Westcot, 1985).

In summary, soil mulching reduced soil evaporation in this high-frequency, drip-irrigated grapevine orchard, and increased the gravimetric soil water content from values of about 17% in the bare soil to values of about 20% in the mulched soils. Soil salinity (EC_e), chloride (Cl_e) and sodicity (SAR_e) were higher in 'Crimson' than in 'Autumn' because of the higher evapo-concentration in the soil of the dissolved salts in the irrigation water derived from its lower field-wide leaching fraction (LF). Soil EC_e, Cl_e and SAR_e systematically increased along the irrigation seasons, but the increases were much lower in the mulched than in the bare soils because of their lower evaporation losses. Thus, the absolute EC_e, Cl_e and SAR_e daily increases in 'Autumn' and 'Crimson' 2008 and in 'Crimson' 2009 were on the average 44% lower in the plastic and 76% lower in the organic mulched soils than in the bare soil. In contrast, the bare soil in 'Autumn' 2009 was most efficient for salinity and sodicity control because of salt leaching by a precipitation of 24 mm recorded the day before its final sampling date. Likewise, the higher efficiency of the organic than the plastic mulch in 'Crimson' 2009 was attributed to the leaching of salts by the 104 mm infiltrated precipitation that was otherwise intercepted by the plastic mulch.

Overall, the inorganic and organic mulching materials were more efficient for soil salinity and sodicity control than the bare soil, but the final results were precipitation-dependent so that their relative efficiencies should be assessed on a case-by-case basis. Due to the limited time span of this work (two years for analysis of bare *vs*. plastic mulching and one year for the analysis of bare, plastic and organic mulching), more research involving the long-term effects of inorganic and organic mulches on soil salinization and sodication is needed to further validate these results.

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